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**EFFECTS OF CRYOGENIC TREATMENT ON THE RESIDUAL STRESS
AND MECHANICAL PROPERTIES OF AN AEROSPACE ALUMINUM ALLOY**

by

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ABSTRACT

Investigators at Marshall Space Flight Center (MSFC) are studying the potential benefits of cryogenic treatment for aerospace Aluminum (Al) alloys. This paper reports the effects of cryogenic treatment on residual stress, tensile strength, hardness, fatigue life, and stress corrosion cracking (SCC) resistance.

INTRODUCTION

Al alloys have long been of interest to the aerospace community, due to their modest specific strength, ease of manufacture, and low cost. Fusion welding is a common method of joining these alloys. However, such techniques can generate defects and high residual stresses. Defects are detected with standard nondestructive evaluation (NDE) techniques. However, residual stresses may generate cracks following proof testing, adding significant costs and schedule delays as repair, inspection, and proof cycles must be repeated.

Methods are continually being sought to improve the weldability of Al alloys for aerospace applications. At MSFC, attempts are being made to determine how cryogenic treatment affects residual stress, tensile strength, hardness, high cycle fatigue (HCF), and SCC resistance. Reports published in the United States and Europe suggest that cryogenic treatment may have the potential to relieve residual stress without sacrificing tensile strength. Treating tool steels at a low temperature near -320 °F (-196 °C) may result in improved mechanical properties, wear resistance, dimensional stability, and tool life.^{1,2} Recent claims have also been made that cryogenic treatment can improve the material properties of copper, high-temperature alloys, carbides, plastics, and composite materials.³⁻⁵

TECHNICAL APPROACH

Cryogenic treatment was applied to an Al alloy that had already been heat treated or welded, as follows:

- Slowly cool without thermal shock to approximately -300 °F (-184 °C).
- Hold at approximately -300 °F (-184 °C) for 24 hours.
- Reheat slowly without thermal shock to ambient temperature.

Test temperatures were reduced from ambient to -300 °F (-184 °C) using liquid nitrogen (LN₂) to significantly slow atomic and molecular activity in the material. Slow temperature changes cause thermal compression and expansion to occur equally from the core to the surface, releasing residual stresses and homogeneously stabilizing the alloy. This process may take 48 hours or longer to keep the entire mass in equilibrium throughout temperature cycling.

EXPERIMENTAL PROCEDURES

This study used rolled plates with a thickness of 1.85 inch (4.7 cm). The material was solutionized and stretched 3% at ambient temperature. Variable Polarity Plasma Arc (VPPA) welding was conducted with the weld bead perpendicular to the rolling direction. As-welded and cryogenically treated weld specimens were then prepared to allow comparison of test results. Residual stress was measured before and after cryogenic treatment. The Bragg law states:

$$n\lambda = 2d\sin \theta$$

where n is an angle denoting the order of diffraction, λ is the x-ray wavelength, d is the lattice spacing of crystal planes, and θ is the diffraction angle. These measurements allow the residual stress state to be evaluated. Here, the X-ray diffraction method was used to calculate the d spacing by measuring the shift of reflected angle θ .

Tensile tests were performed at ambient temperature using round specimens. SCC specimens were tested in the short transverse (ST) orientation at 50% and 75% of yield strength. Three specimens were tested for each condition in a 3.5% NaCl alternate immersion solution per ASTM G44. Unstressed specimens were removed for tensile testing after exposures of various durations.

RESULTS & DISCUSSION

• Residual Stress Analysis

As-welded specimens contained significant amounts of residual stress near the fusion line in the heat affected zone (HAZ). Cryogenically treated specimens showed residual stress reductions of up to 12 ksi in the HAZ. Figure 1 shows no significant changes in the weld bead, fusion line, or parent metal.

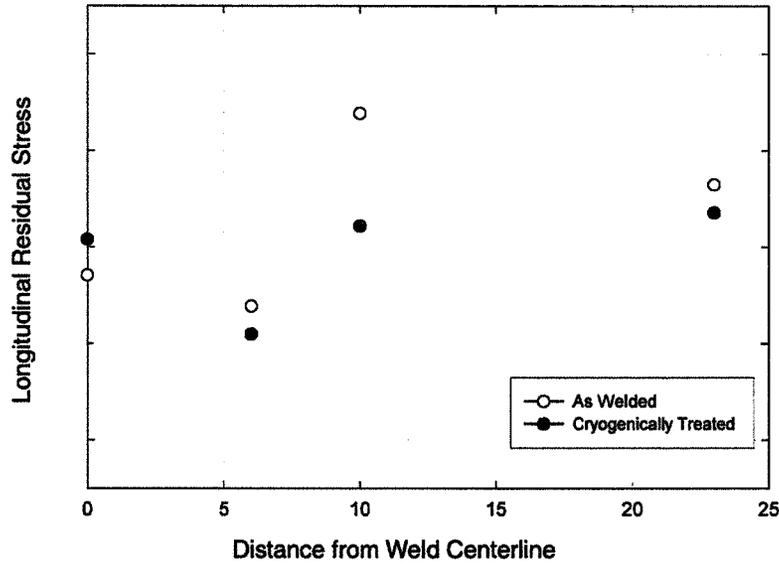


Figure 1. Longitudinal residual stress distribution across a VPPA welded panel

Figure 2 indicates that residual stress was reduced by up to 9 ksi when cryogenic treatment was conducted prior to artificial aging for the rolled plate.

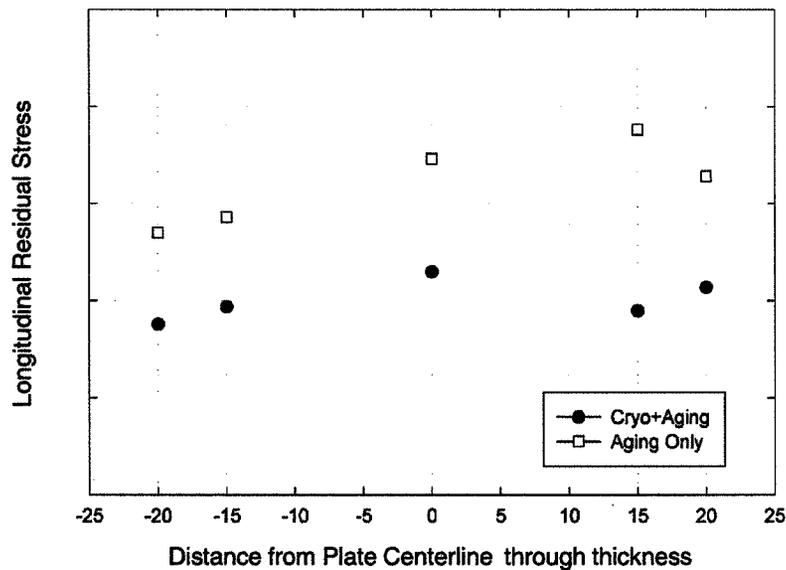


Figure 2. Residual stress profiles for rolled plate with a thickness of 1.85 inch (4.7 cm), with and without cryogenic treatment

- **Tensile and Hardness Tests**

Average hardness increased for parent metal that was artificially aged and then subjected to cryogenic treatment. No significant differences were seen in tensile strength for as-welded and cryogenically treated specimens.

- **High Cycle Fatigue (HCF) Tests**

HCF testing was performed at ambient temperature for as-welded and cryogenically treated specimens. Figure 3 indicates that no noticeable improvements were seen in cryogenically treated specimens.

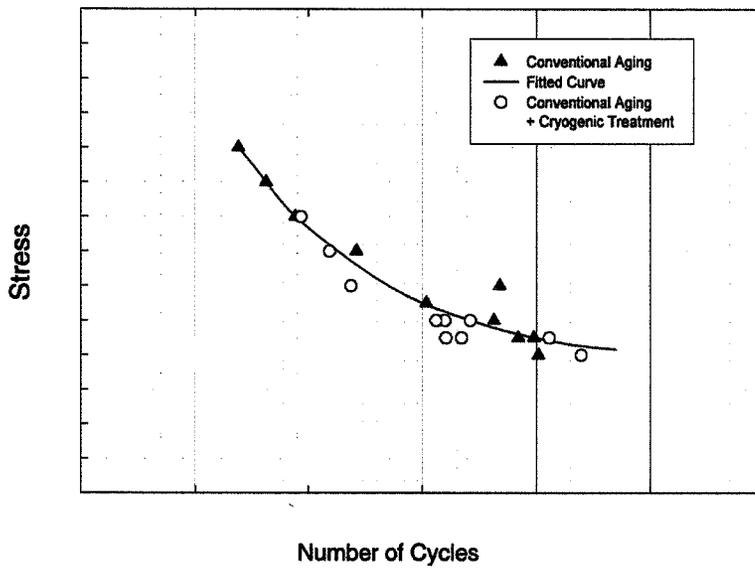


Figure 3. HCF strength

- **Stress Corrosion Cracking (SCC) Tests**

Table 3 shows significant improvements in SCC lives for cryogenically treated specimens.

Table 3 - Stress Corrosion Results for Weld Specimens

Specimen Condition	Stress Level (%YS)	Failure Ratio	Highest Residual Stress in HAZ	Days to Failure
As-welded	50	1/3	23.9 ksi	65
	75	2/3		3, 6
Cryogenically treated	50	0/3	12.2 ksi	--
	75	2/3		22, 84

CONCLUSIONS

The following results were observed for this particular Al alloy after cryogenic treatment:

1. Residual stress was reduced by up to 12 ksi in the HAZ of weld specimens and by up to 9 ksi in parent metal.
2. Significant improvements in SCC performance were seen for weld specimens.
3. Minor increases in tensile strength and hardness were noted for parent metal.
4. No significant changes were found in tensile properties for weld specimens or in fatigue properties for parent metal.

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